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THE INSTALLATION AND CORRECTION OF COMPASSES IN AIRPLANES

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Introduction

The saving of time that results from flying across country on compass headings is beginning to be widely recognized. At the same time the general use of steel tube fuselages has made a knowledge of compass correction much more necessary than was the case when wooden fuselages were the rule.

This paper has been prepared primarily for the benefit of the pilot who has never studied navigation and who does not desire to go into the subject more deeply than to be able to fly compass courses with confidence. It also contains material for the designer who wishes to install his compasses with the expectation that they may be accurately corrected.

### I. Causes of Compass Errors

The most common causes, due to which airplane compasses fail to indicate the true north are:

- (a) Magnetic variation;
- (b) Magnetic deviation;
- (c) Vibration;
- (d) Faulty compass.

MAGNETIC VARIATION is the name generally given in the United States to the angle by which a completely undisturbed magnetic compass fails to point to the true north. Magnetic variation is frequently called "declination" in the Army Air Corps and in Europe. It is due to the fact that the north magnetic pole of the earth lies in Northern Canada and not at the true north pole.

MAGNETIC DEVIATION is the name given in the U. S. Navy to the effect of the Magnetic Materials of the airplane upon the compass.

VIBRATION of the airplane, if sufficiently severe, may cause jumping or even spinning of the compass while the airplane is in straight flight.

The most common causes of a FAULTY COMPASS are:

- (a) Loss of liquid;
- (b) Pivot off the jewel;

- (c) Canted card;
- (d) Cracked jewel.
- (e) Blunted pivot.

## II. Discussion and Elementary Explanation of the Causes of Error and the Methods of Correction

### (a) Compass Marking.

As a preliminary it should be said that all American compasses are marked on the following general system:

North is called	0 degrees
Northeast is called	45 "
East " "	90 "
Southeast " "	135 "
South " "	180 "
Southwest " "	225 "
West " "	270 "
Northwest " "	315 "

In other words, all directions are given in degrees of a circle, north being 0, and the angle being measured to the right from north. It is common to mark the card as follows:

North is marked	N
30° " "	3
60° " "	6
East " "	E

and so on around the card, with unmarked lines at each  $5^{\circ}$  interval. Since airplane compasses are mounted ahead of the pilot; the figure N is actually on the south side of the card and the figure S on the north side, but the system remains the same. This is illustrated in Figure 1.

(b) Magnetic Variation.

MAGNETIC VARIATION is the angle by which a completely undisturbed compass fails to point to the true north. It is not a constant angle, but varies throughout the world. THE COMPASS CANNOT BE CORRECTED FOR VARIATION; it is necessary for the pilot to know the variation for the general region in which he is flying. It does not change very rapidly. In general, it will not change more than about 1 degree in a 100-mile east-west flight, and much less in a north-south flight. The value of the variation is marked on the aeronautical strip maps issued by the Army Air Corps and the Naval Hydrographic Office and is marked on most good commercial maps. On the Army maps it is generally marked in red on the edge of the map, and is given without a name, as " $7\frac{1}{2}^{\circ}$ ". The variation is given as, for example, "6 degrees easterly" or "10 degrees westerly." Easterly variation means that the compass needles are pulled to the east or right of the true north, and therefore the compass reads less than it should by the number of degrees of variation. For instance, suppose the variation is  $5^{\circ}$  E, and it is desired

to find the compass heading corrected for variation corresponding to a true heading of  $45^{\circ}$ . This corrected heading, which is known as the MAGNETIC HEADING, is then  $45^{\circ}$  minus  $5^{\circ}$  equals  $40^{\circ}$ . If the variation is westerly, it is added to the true heading to find the magnetic heading. The Army Air Corps strip maps have marked alongside the courses from place to place the value of the magnetic course. This means that the variation has already been applied to the true course and it is not necessary for the pilot to apply the variation correction.

In case no values of the variation can be found on the map to be used, the pilot can determine it with fair accuracy on the ground by the following method: Set a compass on the ground at least 50 feet from any large masses of steel or iron, or electric wires. Line up the lubber lines of the compass carefully on true north and south by sighting them on the North Star, or by aligning them on streets or section lines which are known to run due north and south. After the compass has steadied down, read the compass. If it reads, for example,  $30^{\circ}$ , the variation is  $30^{\circ}$  west. If it reads, for example,  $330^{\circ}$ , the variation is  $30^{\circ}$  east. It will be noticed that in the first case the needles have been pulled to the west of true north and in the second case to the east of true north, hence the names westerly and easterly (Fig. 2). After taking a reading it is advisable to move the compass about 20 feet to see if the two readings check as the compass may have been accidentally placed

over a buried pipe line or other mass of iron.

Actually the variation is now  $20^{\circ}$  westerly in eastern Maine and decreases to 0 on the general line Saginaw, Cincinnati, Savannah, and then increases to  $26^{\circ}$  easterly in the state of Washington.

(c) Magnetic Deviation.

MAGNETIC DEVIATION is the compass error due to the presence of iron or steel or to the effect of electric wiring in the airplane. It varies with each direction in which the airplane is headed, but it can be corrected nevertheless, and the compass made to read magnetic headings or within 2 or 3 degrees of magnetic headings.

Without going at all deeply into the theory, the following simple explanation can be given. Suppose one of the longerons forward of the compass has become magnetized in some way with a north pole near the nose and a south pole nearer the compass. Then, when the airplane is headed north, this south pole in the longeron will attract the north pole of the compass needle and hold the compass on north more strongly than usual. When the airplane is headed east, the compass magnets should lie directly athwartships, but the south pole in the longeron will pull the north end of the magnets to the east and cause an EASTERLY DEVIATION (so-called because the compass needles have been pulled to the east). When the airplane is headed south, the south pole in the longeron will tend to repel the south pole of the compass

needle, which pole is now toward the nose of the airplane and will weaken the effect of the earth's magnetism.

When the airplane is headed west, the compass needles should again lie athwartship, but the south pole in the longeron will pull the north pole of the compass needles to the west this time and cause a WESTERLY DEVIATION (so-called because the needles have been pulled to the west of north).

Figure 3 may make this more understandable. It must be understood that had the longeron become magnetized with its south pole forward, the effect would be just opposite.

This is far from being the complete theory but illustrates one of the commonest cases of deviation in airplanes.

The deviation can be easily corrected by putting small COMPENSATOR MAGNETS in the compass which will give an effect equal and opposite to that of the iron of the airplane.

All Navy and most commercial compasses have underneath the compass two tubes, one fore and aft and one athwartships, in which these compensator magnets may be placed. The Army instrument-board-mounting compasses have these tubes on top. These tubes are usually covered by a cap held in place by two screws. Back off these screws and turn the cap a bit; the tubes will then be uncovered and the magnets can be placed in them and then held in place by resetting the cap and screws.

Compensator magnets are always furnished with new compasses or can be obtained from compass manufacturers.



The method of placing the magnets is as follows:

Head the airplane accurately on magnetic north (true north corrected for variation). Put magnets in the ATHWARTSHIP tube until the compass reads north. If a magnet is put in and it makes the error worse take it out and put the other end in first. Magnets of varying strengths are usually furnished, but if no magnet can be found that is not too strong, break one in two, tap it on its end a few times and try it. Use the athwartship tube because the best way to close a door is to push at right angles to it, not along it.

Then head the airplane east magnetic ( $90^{\circ}$  from north magnetic) and put compensator magnets in the fore and aft tube until the compass reads east.

Most of the work is now done.

It may not be possible to find a combination of magnets which will make the compass read exactly north and east. In that case try to get it within 2 or 3 degrees short of the point which is being tried for. If the compass is pushed past the point it is OVER COMPENSATED and will be sluggish.

Now swing to south magnetic. If the compass reads exactly north on north magnetic it should read south on south magnetic. If it does not read south, change the athwartships magnets to take out half the error. If it reads say  $2^{\circ}$  west deviation ( $2^{\circ}$  reading) on north magnetic it should read  $2^{\circ}$  east deviation ( $178^{\circ}$  reading) on south magnetic. If the same deviation in the

opposite direction is not found on south magnetic as on north magnetic, change the athwartships magnets to take out half the difference. For instance, suppose the deviation on north magnetic was  $2^{\circ}$  west ( $2^{\circ}$  reading) but instead of being  $2^{\circ}$  east ( $178^{\circ}$  reading) on south magnetic, it is  $6^{\circ}$  east ( $174^{\circ}$  reading). In such a case change the athwartship magnets to give  $4^{\circ}$  east deviation ( $176^{\circ}$  reading) on south magnetic.

Now swing to west magnetic. If the compass reads east on east magnetic it should read west on west magnetic. If it does not read west, change the fore and aft magnets to take one-half the error. If  $3^{\circ}$  easterly deviation ( $87^{\circ}$  reading) was found on east magnetic, a  $3^{\circ}$  westerly deviation ( $273^{\circ}$  reading) should be found on west magnetic. If the deviation on west magnetic is not the same in the opposite direction as on east magnetic, take out half the difference as was done on south magnetic.

After having checked on north, east, south and west, it is advisable to head the airplane on at least every 45 degree magnetic heading, that is, on

North magnetic

$45^{\circ}$       "

East      "

$135^{\circ}$       "

South      "

$225^{\circ}$       "

West      "

$315^{\circ}$       "

or better still, on every 30 degree magnetic heading and find what error remains. Even if the compensation has been perfect on north, east, south, and west, small errors may still exist on the other headings due to the existence of factors not discussed here.

The errors which are found on this complete swing should then be put in the form of a table and the table posted where it can be readily seen. One of the handiest forms is given below:

Magnetic Head	Compass Head
North	2°
30	33
60	62
East	90
120	119
150	149
South	178
210	209
240	241
West	270
300	302
330	332

In order to place the airplane on the desired magnetic headings it is necessary to lay out these headings. This can be easily done by setting a compass on the ground about 50 feet

from any large masses of steel, and setting out two pegs accurately placed on the north-south line indicated by the compass. The pegs should be placed a distance apart about twice the length of the airplane to be swung. Then with the distance between these pegs as a diameter lay out a circle and mark it off in degrees with pegs at every  $45^{\circ}$ , or better, every  $30^{\circ}$ . In getting the magnetic north-south line of this COMPASS ROSE, care should be taken to see that there are no compensator magnets in the compass compensator tubes.

In getting the compass error on the various headings it is important that the control stick, if of steel, be held in the approximate level flight position and that, if the fuselage is of steel, the tail be lifted until the fuselage is in the approximate level flight position. For accurate work it is desirable to have the engine warmed up and running while getting the compass error, but it is very seldom that this is really necessary.

Placing the compensator magnets in the tubes can be made much easier by using a pair of brass tweezers to handle the magnets as they will not stick to brass.

If the deviations are found to be  $5^{\circ}$  or less before the compensator magnets are put in, it is better not to compensate at all, but just to swing the airplane on the various magnetic headings and make a table of the deviations. Using the compensator magnets always makes a compass somewhat more sluggish. If any of the deviations are over  $30^{\circ}$  it is best to try to find a

new location for the compass, as compensating such a deviation will make the compass very sluggish. It will be frequently found that moving a compass a few inches away from steel parts will improve it tremendously.

After the compass has been compensated it may be checked from time to time by lining the airplane on a known heading or while flying in smooth air over streets or section lines whose direction is known and allowing for drift. If steel wires which vibrate a good deal are close to the compass, say within a foot of it, the deviation may change considerably after long flights, as vibration of steel gives ideal conditions for changing its magnetism. In one case a deviation was found to increase  $16^{\circ}$  after a long flight. After an airplane has been in service for some time and has been well shaken down, not much change in deviation due to vibration need be feared.

If flights of a thousand miles or more north or south are to be made the deviation may be expected to change a few degrees due to parts of the theory not given here. Usually this effect can be neglected.

#### (d) Vibration.

In addition to the effect of vibration on deviation, vibration may have another and much more serious effect, that is, to cause jumping or spinning. Once this jumping is seen it is very easily recognized, as the card will be seen to jump very

erratically, to swing 20 or 30 degrees to one side very rapidly, to start to swing back, and then to jump and swing off again. If the vibration is very bad the compass may even spin like a top. This vibration jumping should not be confused with the much less jerky and erratic swinging of a compass in bumpy air or while the airplane is being maneuvered. The swinging in bumpy air will average out as in a short time the swings to the left will equal the swings to the right.

Fortunately this vibration jumping does not often appear and even then only at certain engine speeds. It can usually be overcome by making the compass mount more rigid, by making the surface on which it is mounted more rigid, by moving the compass a few inches, or by using one of the anti-vibration mounts now appearing on the market.

The cause of this vibration jumping is very simple. (Refer to Figure 4, which illustrates one type of compass.) At best the earth's magnetism is not very strong. When the parts touch, as shown in the lower diagram, the compass card is given a turning push which is much stronger than the holding force of the earth's magnetism.

#### (e) Faulty Compasses.

One often sees compasses with the card canted and stuck. If this is due to the pivot being off the jewel or to an air bubble having been caught under the card, the condition can frequently be corrected by shaking the compass violently.

The appearance of bubbles means a leaking compass. Bubbles the size of a quarter dollar generally have little effect, but if they become much larger the effect will be bad and the compass should be refilled through the filling plug which is always provided. Some compasses are filled with alcohol water mixtures and some with petroleum derivatives. If the compass to be refilled requires alcohol-water and only bubbles have appeared, add distilled water. If the compass has leaked to such an extent that a free liquid surface has formed, a mixture of 50% alcohol and 50% distilled water should be added. If the compass is filled with a petroleum liquid, any leakage should be made up by adding water-white kerosene. Do not put kerosene in an alcohol-water compass or vice versa for the result is certain to be bad.

A cracked jewel or blunted or broken pivot will cause the card to rotate jerkily or even to stick completely. This condition may be found by holding a magnet near the compass until it has turned about  $10^{\circ}$ . Then take the magnet away suddenly. The compass should return to its original reading within  $2^{\circ}$ .

### III. Installation of Compasses

Whenever possible the compass should be installed on the fore and aft center line of the airplane. The lubber lines must be accurately lined up with the fore and aft center line.

No definite rules can be laid down for the distance of a

compass from magnetic parts to insure a given deviation, as the deviation depends upon the degree of magnetization which the parts have accidentally acquired. However, if the airplane designer keeps the following recommendations in mind, he may confidently expect that the magnetic conditions surrounding the compass will be good.

The following distances should be allowed between the compass and parts, if magnetic:

- (a) Structural rods and wires, 15".
- (b) Fire walls, 24".
- (c) Tanks or floor plates above or below the compass, 15".
- (d) Tanks on the center line ahead of or behind the compass, 24".
- (e) Tanks not on the center line, 30".
- (f) Cowling or instrument board, 24".
- (g) Movable parts, such as the control column, 18".
- (h) Untwisted direct current wiring, 36".
- (i) Essential removable parts, such as cranks and tool kits, 36".
- (j) Engines, as far as is consistent with good visibility of the compass.

If direct current wires are twisted one over the other they have no effect. Alternating current wires have no effect.

To double the distance from a magnetic part decreases the effect of that part to approximately one-fourth of its previous value.



Steel, iron, and terne plate, since the last contains iron, are practically the only magnetic materials used in airplanes. Duralumin, aluminum, brass, bronze, and wood have no magnetic effect whatever, upon a compass.

The compass should be so installed that access to the compensator magnet tubes is easy.

The compass should be secured to a surface which is sufficiently rigid not to magnify the airplane's vibration.

#### IV. Summary

To mount the compass:

See that it is filled, the card not canted, and the card working freely. Line it up on the center line where it is well away from magnetic parts, easily visible, rigidly secured and the compensator tubes accessible.

To compensate the compass:

Stow the tool-kit, crank, etc., where they are usually carried. Head the airplane on magnetic north. Remove the deviation by putting magnets in the athwartship tube. Head the airplane on magnetic east. Remove the deviation by putting magnets in the fore and aft tube. Head the airplane on magnetic south and remove half the deviation. Head the airplane on magnetic west and remove half the deviation. Place the airplane on at least the eight magnetic headings  $45^{\circ}$  apart, beginning with north, and make a table of the compass headings correspond-

ing to the magnetic headings. Whenever the compass reading is being taken the fuselage and controls should be approximately in the position of level flight and the compass should be tapped with the finger.

To check the compass:

Occasionally compare the compass reading, when the airplane is on a known magnetic heading, with the value given on the table.

The small amount of work required in compensating a compass will be well repaid by the resulting ability to fly across country without following railroads.

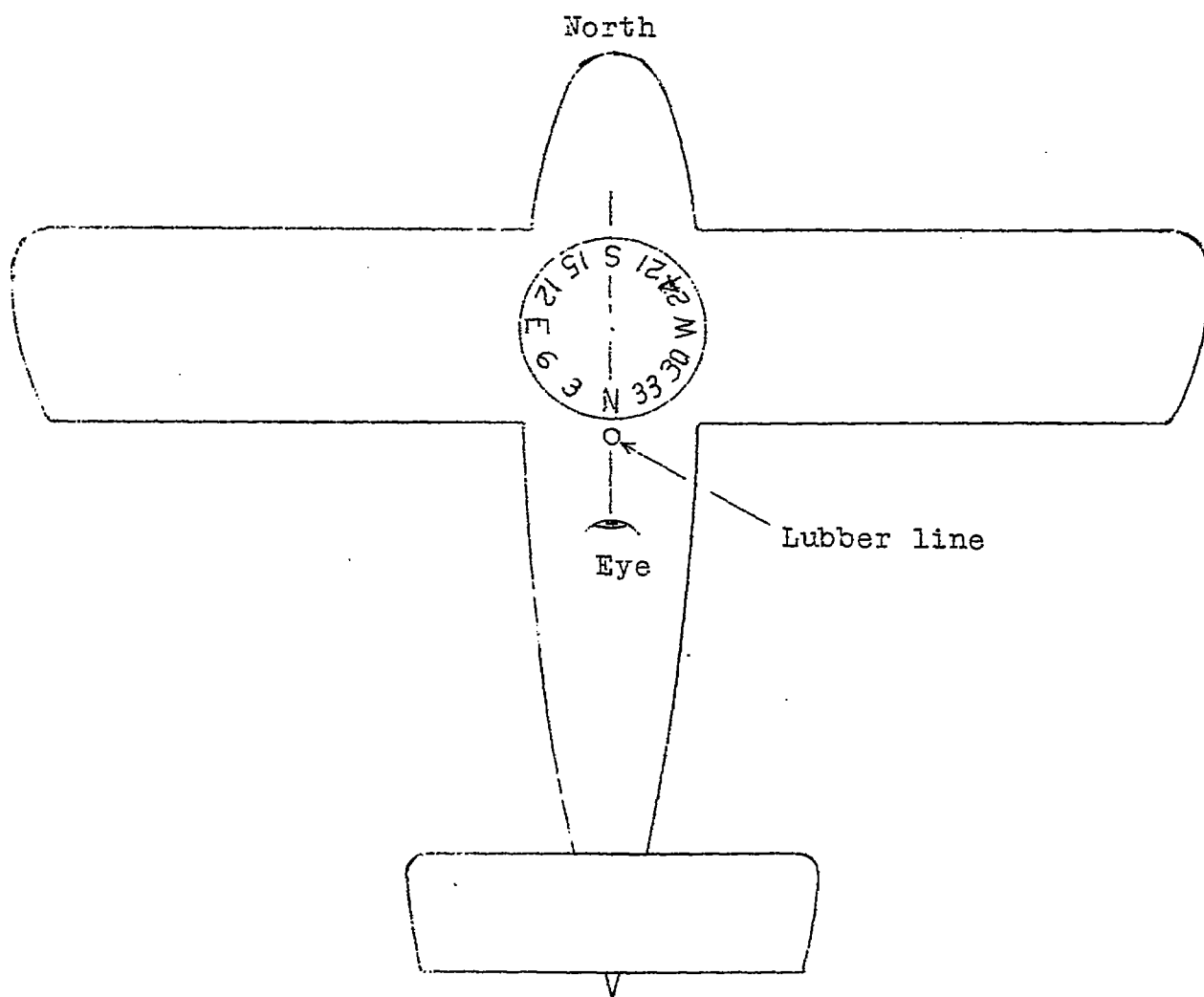


Fig. 1

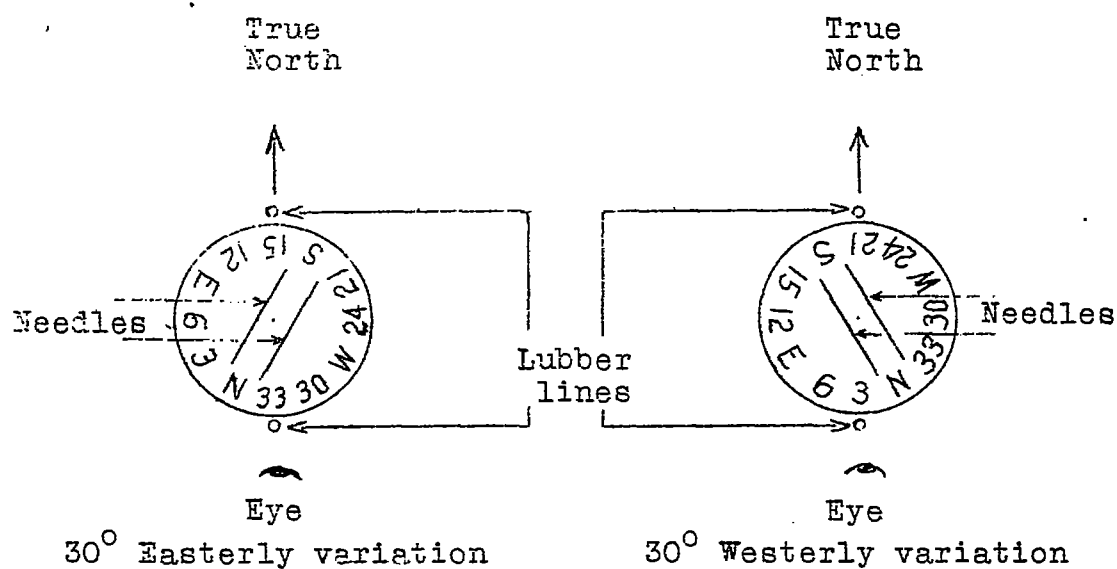


Fig. 2

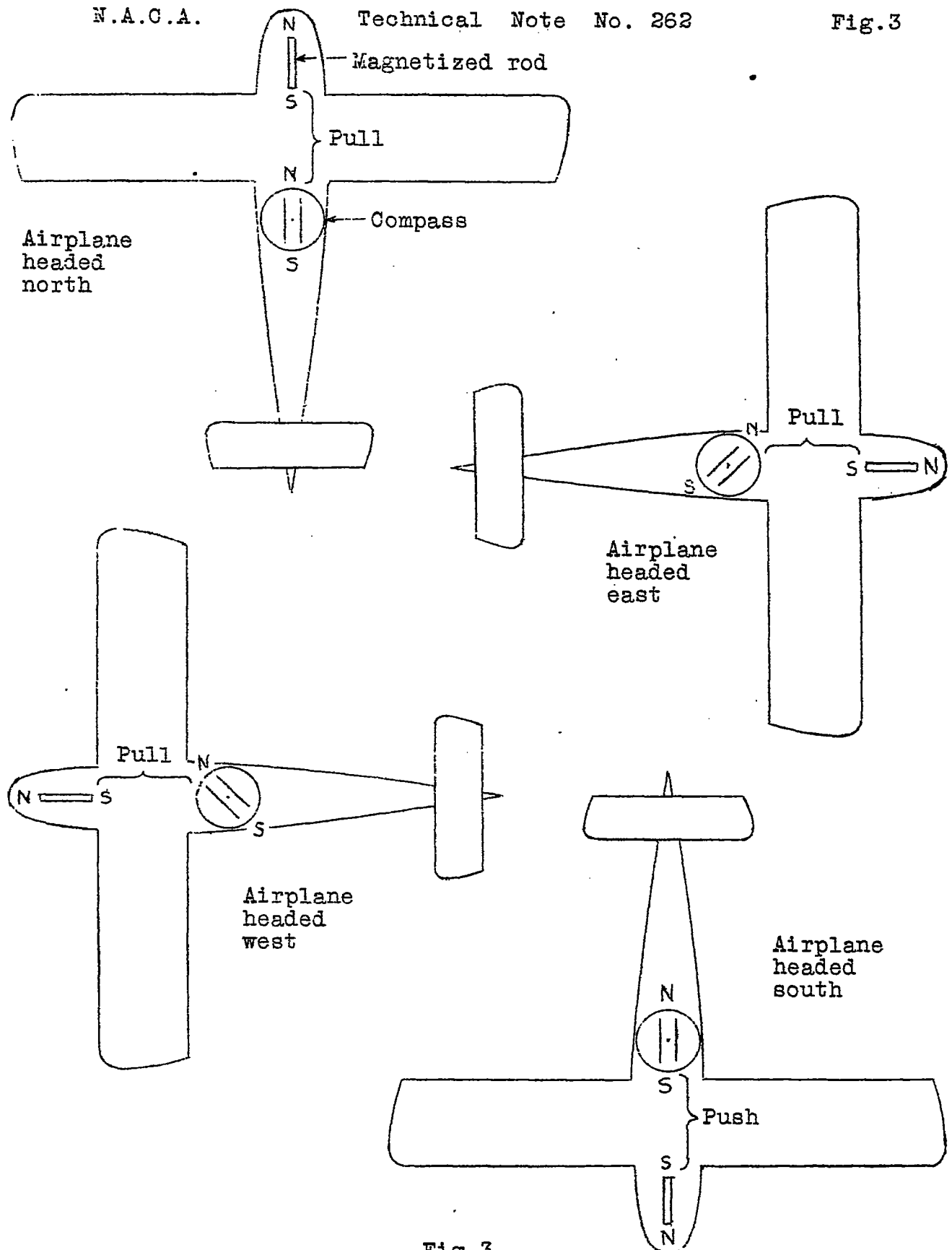


Fig.3

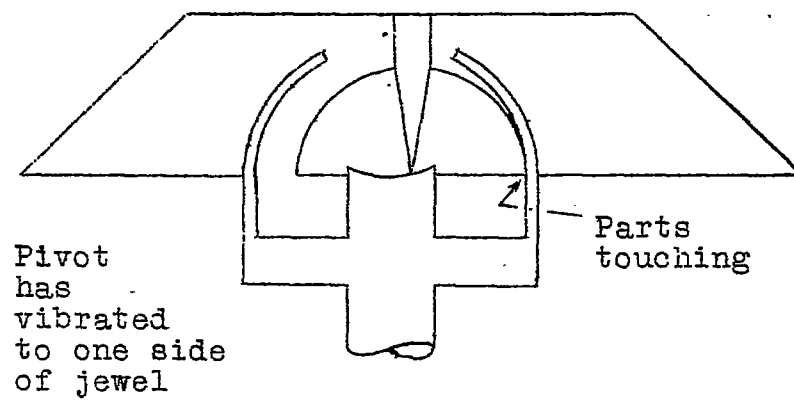
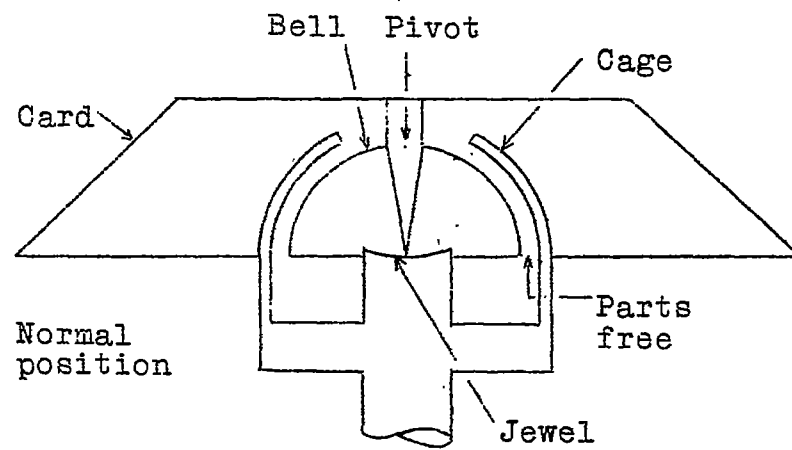


Fig. 4